

Overview of the NASA Systems Approach to Crashworthiness Program

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Abstract

The NASA Aviation Safety Program was developed in response to the federal government's goal to reduce the fatal accident rate for aviation by 80% within 10 years. Accident Mitigation is a primary element of the Aviation Safety Program. The overall Accident Mitigation goal is to provide technology to the air transport industry to enable a decrease in the rate of fatalities and injury from crash loads and from in-flight and post-crash explosion and/or fire. Accident Mitigation is divided into two main elements - Fire Prevention and Systems Approach to Crashworthiness. The Systems Approach to Crashworthiness goal is to develop and promote technology that will increase the human survival rate or reduce the fatality rate in survivable accidents. The technical background and planning, selected technical activities, and summary of future efforts will be presented in this paper.

Introduction

According to the Gore Commission final report, the worldwide demand for air travel is expected to double or triple by 2017 with the requirement for \$1 trillion in new aircraft deliveries [1]. Without decreasing the accident rate, such a traffic volume would lead to 50 or more major accidents a year. Given the very visible, damaging, and tragic effects of even a single major accident, this number of accidents would clearly have an unacceptable impact upon the public's confidence in the aviation system and impede the anticipated growth of the commercial air-travel market. President Clinton announced in

February 1997 a national goal to reduce the fatal accident rate for aviation by 80 percent within 10 years.

In response to the presidential announcement, NASA initiated the Aviation Safety Investment Strategy Team (ASIST), which sponsored four industry- and government-wide workshops to define research needs. The planning effort lasted from February to April 1997, and involved over 100 industry, government, and academic organizations. A subset of the research investment areas from ASIST, denoted Human Survivability, formed the basis for the technical activities within NASA's Aviation Safety Program (AvSP) Accident Mitigation (AM) element. Human survivability included the areas of mitigating the impact and fire effects of an accident and in-flight fire prevention. The official start of the AvSP was FY 2000. Prior to the start of

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the AvSP, Crashworthiness and fire prevention were included in the Airframe Airworthiness Assurance (AAA) program. AAA provided the opportunity to upgrade computational capabilities, increase instrumentation inventories, purchase mechanical equipment, fund survey reports on transport, rotorcraft and general aviation accidents and a fuel system report [2,3,4,5], hold workshops with industry and the Federal Aviation Administration (FAA), and conduct analyses and testing. Based on these survey reports, industry and FAA input, and in-house efforts, the plans for the AvSP AM were developed.

AvSP emphasizes not only accident rate reduction, but also a decrease in injuries and fatalities when accidents occur. The AvSP goal is to develop and demonstrate technologies that contribute to a reduction in aviation accident and fatality rates by a factor of 5 by year 2007 and by a factor of 10 by year 2022.

To reach the goal of reducing injury and fatality rates in accidents, understanding the crash environment is required. For occupants to survive a crash of an aircraft, a number of things must happen. The majority of the impact energy must be absorbed by the airframe structure and seat. The restraints must function well during the primary and secondary impacts (eg. minimize head strikes). The seat must remain attached to the floor. An egress path must remain available and there must be enough time for the occupants to egress before fire and smoke become incapacitating. Therefore, the Systems Approach to Crashworthiness plan is divided into three sub-elements that

focus on specific functions to meet the program objectives. The first sub-element is crash load predictions using finite element modeling. The second sub-element, occupant protection, includes developing design approaches, standards, and materials for protecting occupants from crash loads. Crash resistant fuels systems (CRFS) is the third sub-element. CRFS includes design approaches, standards, and materials for protection against rupture of fuel system tanks, lines, and other components.

The Systems Approach to Crashworthiness plans include partnering with customers to accomplish the end goals. The partners include the Federal Aviation Administration, U.S. Army, analytical code vendors, seat and restraint manufacturers, airframe manufacturers and fuel system manufacturers.

A more detailed description of the technical approach and work being conducted in each sub-element is presented in the following sections.

Crash Load Predictions

In the last ten years, significant advances have occurred in computing capabilities, data acquisition systems, and finite element simulation. These technical advances provide the ability to effectively evaluate detailed finite element models. For the aircraft industry, use of finite element codes in designing crashworthy structures has not proven cost effective. In addition, no procedures or regulatory guidelines have been established for use of codes in the crashworthiness certification process. Certification for crashworthiness relies

solely on seat tests [6,7,8]. A full-scale crash test could be an option to certify an aircraft design that utilizes the systems approach. However, this approach is not accepted as an economically viable method due the manufacturing cost. Also, there is a disconnect between the designer's needs and the certification process. The designer needs loads and displacements to size structure or design energy absorbing structure. The certification process needs the input floor acceleration pulse and occupant response information. No method to quantify the accuracy of the models is currently available. To address these issues, the crash load prediction efforts include best practices in analytical model development, guidelines and standards for test and analysis correlation, enhancement of the analysis codes for use as design, and certification tools.

Best Practices

The best practices in analytical model development work is based on modeling of complete aircraft as presented in Figure 1.[9], fuselage sections shown in Figure 2. [10], outside customer projects [11], and small-scale lab experiments [12]. The structures are composed of composite, metallic, or hybrid materials. Data are being compiled for a report on the effective methods for developing detailed finite element crash models. The information will be updated as necessary. These documented data are intended to help the user develop the best model in a reasonable time by avoiding approaches that do not work. Examples of best practices to be included in the document

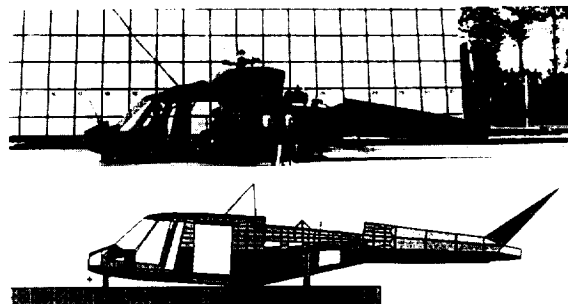


Figure 1. Composite helicopter full-scale crash test and analytical model.

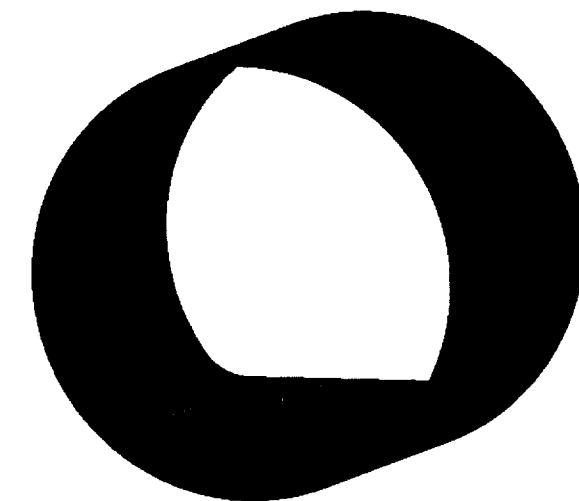
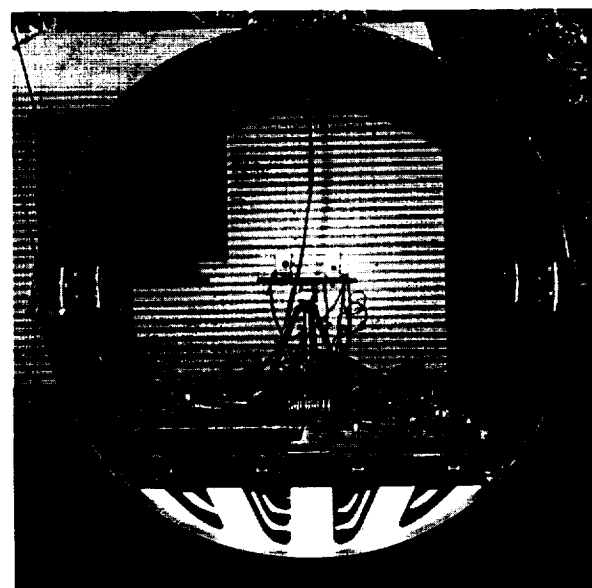


Figure 2. Energy absorbing fuselage test article and analytical model.

range from how to prevent geometric discontinuities, to the importance of accurate material properties [13]. Ultimately, these practices should be used to develop a full aircraft model used for designing and certifying crashworthy aircraft. One approach for this would require testing but the testing could be limited to a fuselage sections or critical components of the aircraft structure. Experimental data from these component tests would be compared analytical results. If the correlation validates the component analysis and the full aircraft model is developed with the same practices, confidence is increased for the validity of the full aircraft simulation.

Test Analysis Correlation (TAC)

Guidelines and standards for test analysis correlation are needed to quantify the accuracy of the model simulations. Along with the computational capabilities, significant advances have occurred in data acquisition systems. Digital data acquisition systems are capable of recording multiple channels and millions of data points at rates exceeding 10khz. Analytical models with tens of thousands of elements are common in crash simulations and the computational resources used to run the simulations on desktop personal computers. However, oftentimes the assessment of the correlation accuracy is based on the qualitative comparison of time history response. These comparisons provide valuable information with regard to the global response of the aircraft [10]. Unfortunately, the global responses do not meet all of the information requirements of the aircraft designer and the certification process.

Historically, when full-scale aircraft or sections of aircraft were tested, instruments were mounted to give information on the performance of a concept. As the test and analysis correlation requirements and expectations change, the instrumentation of the test article must evolve to provide the data needed. For example, there are usually many accelerometers located on the floor structure and on large masses. However, these data give little information on the load path through the structure below the floor. The ability to correlate the predicted and test loads in main structures in the wing box area would be advantageous to the designer. This information could be used to identify structural members that need to be modified. However, obtaining this information from a test is not straightforward. Strain gages, though excellent for use in quasi-static testing, offer little useful information in a full-scale crash test. Part of the TAC effort is focused on development of instrumentation for use in the crash environment. Other TAC efforts involve using the crash simulation results as a guide for instrumentation layout, efficient data reduction processes and automated data handling for performing correlation studies in a timely manner.

The main TAC goals are to identify what data should be correlated and to develop methods to quantify the accuracy of the analytical predictions. While investigating typical comparisons of accelerations, it was found that the filtering frequency affects the correlation accuracy. The standards for filtering data were established before the digital data acquisition systems were available. Standards for selecting the filtering

frequency need to be addressed [14]. Or, another approach being investigated involves acquisition of data that are less noisy or that do not need filtering, such as displacements. Again, this approach will require instrumentation development.

In addition to pursuing new methods to correlate simulation and test data, literature searches and trials of other methods outside the crash field of study are being conducted. The final TAC product should: identify the data to be correlated; define processes for the collection and post-processing of the test data; provide methods to retrieve and post-process data from the simulation; and define a method for comparisons of the data that include calculations and the presentation of the correlation in a logical, quantifiable, and simplified manner.

Code Enhancements

Enhancement of analysis codes includes identifying deficiencies in the codes and new capability requirements, identification of errors in theory or computing, and identification of post-processing or output file anomalies. An example of a deficiency would be the lack of a typical element type. An example of a post-processing anomaly is aliasing resulting from the insufficient sampling of time history results. These are a few of the types of enhancement needs encountered by the in-house researchers.

Certification Issues

The certification issues of a systems approach aircraft design are being actively worked. Under a joint

Memorandum of Agreement [15], NASA and the FAA are working together to define the expectations of a process to certify an aircraft for crashworthiness by analysis. The FAA is actively funding efforts in crash analysis [16]. Regularly scheduled meetings and teleconferences with the FAA on certification issues are planned. Validation of the simulations has been identified as a critical issue by NASA. Demonstrations of the processes in actual test and simulation correlation studies are expected to be the resolution for many of the concerns. A full-scale crash test of a Fokker 28 aircraft is scheduled for March 2004. A photo of the test article is presented in Figure 3. Modeling and testing of Fokker 28 fuselage sections are planned to demonstrate the previously discussed methods and processes. The successful methods and processes will be used in the full aircraft model. The FAA will be informed and involved with this test series. Results from this work are expected to guide the follow-on work.



Figure 3. Fokker 28 aircraft scheduled to be crash tested in 2004.

Occupant Protection

The occupant protection functions are to reduce the injury frequency and severity and to increase

the proportion of occupants escaping a survivable accident. This function is hardware development and injury mechanism identification. Hardware development includes: material characterization testing; energy absorbing structural concepts; controlled aircraft break-up technology; floor structural integrity; restraints; seat technology; aircraft layout; and sensor technology for collection of data during accidents. NASA develops energy absorbing materials and structures technology for aircraft and space applications [17,18,19]. An energy absorbing subfloor design is presented in Figure 4. An energy absorbing concept for a Mars Sample Return structure is shown in Figure 5.

In addition to the in-house efforts, NASA is utilizing other means to motivate the industry and universities to be involved in crashworthiness technology development: Small Business Innovative Research contracts; and National Research Announcements.

Occupant protection activities include providing information to the designer on crash physics, biometrics, current seat and restraint design considerations, delethalization of the interior, and post-crash factors. This information will be in the form of design guides similar to those developed by the U.S. Army [20]. Two design guides are planned. The first is a general aviation design guide that is to be published in 2002. The second is a transport design guide that is a deliverable at the end of the program. It is expected that these documents will be updated as technology progresses.



Figure 4. Energy absorbing subfloor structure during dynamic test.



Figure 5. Energy absorbing Mars sample return concept.

To assist the efforts in injury mechanism identification and as previously mentioned, surveys of transport, general aviation and rotorcraft accidents were generated [2,3,4]. In the case of the transport survey of survivable accidents, the data collected at the accident sites and medical facilities did not provide complete information on injuries. It is critical to crashworthiness efforts that the types of injuries and the mechanisms that caused them be identified. For example, if lower leg fractures are occurring due to seat collapse and are preventing or slowing egress and the results are fatalities due to smoke inhalation, this information needs to be reported in the post-crash system. However, the National Transportation Safety Board (NTSB) does not focus on this information. The charter of the NTSB is to focus on the cause of the accident. Therefore, NASA and the FAA are collaborating with the NTSB to enable the acquisition of this information.

Crash Resistant Fuel Systems

The crash resistant fuel systems (CRFS) functions are to decrease the chance of a post-crash fire and/or slow the post-crash build-up of fuel fire, smoke and heat to increase time for egress. A study of transport airplane crash resistant fuel systems was documented [5]. In the study, a list of recommendations was generated. The recommendations include: a need for a crashworthiness rating system for fuel systems; materials improvements; use of breakaway and self-sealing technology; development of fuel bladder technology suitable for transport aircraft; and development of frangible fastening

methods. Work in CRFS is being initiated through the National Research Announcement process with the FAA providing oversight. Design and manufacturing expertise of aircraft fuel systems resides with the FAA and industry. NASA will work with the FAA and industry to provide structural expertise for new concepts. NASA plans to provide the Fokker 28 for concept evaluation testing of wet wing designs.

Concluding Remarks

The purpose of this paper is to review the historical and technical background of the Systems Approach to Crashworthiness element of the Aviation Safety Program. The paper summarizes the basis for the planning and execution of the technical efforts. The aircraft structure forms a system in which all components work together to protect the occupant in a survivable crash. To be able to design an aircraft by this method, it must be cost effective. A three-part approach has been developed. The first part is the crash loads predictions and has the potential to benefit all classes of aircraft. NASA is working on developing tools, methods, instruments, and processes that will make it feasible to produce a finite element model and crash simulation that is acceptable for certification and has design capabilities. The second part is investment in the technologies that can be tailored for use in the system being designed. Materials, structures, seats and restraints are a few of the hardware research areas. Also, it is necessary to have injury mechanism information that is accurate and complete. The third part is crash

resistant fuel systems. Fire, smoke and heat are threats in all accidents.

The Systems Approach to Crashworthiness work is a team effort. The team includes NASA, FAA, Army, service contractors, general aviation manufacturers, rotorcraft manufacturers, transport industry, suppliers, and universities. The success of this program is dependent on the ability of these team members to work toward the goal of safer aircraft.

References

1. Gore Commission, "Final Report to President Clinton and White House Commission on Aviation Safety and Security," Washington, D.C., February 12, 1997.
2. Grierson, Anita E., "Final Report - Recommendations for Injury Prevention in Transport Aviation Accidents," Simula Technologies, Inc. TR-99112, February 2, 2000.
3. Baldwin, Mark, "Final Report - A Systems Approach to General Aviation Occupant Protection," Simula Technologies, Inc. TR-00046, June 19, 2000.
4. Baldwin, Mark, "Final Report - Recommendations for Injury Prevention in Civilian Rotorcraft Accidents," Simula Technologies, Inc. TR-00016, February 29, 2000.
5. Robertson, S. H., Johnson, N. B., Hall, D. S., Rimson, I. J., "A Study of Transport Airplane Crash-Resistant Fuel Systems," DOT/FAA/AR-01/82 or NASA/CR-2002-211437, March 2002.
6. "Federal Aviation Regulations, Part 23, Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes," Section 23.562 Federal Aviation Administration, Washington, D.C.
7. "Federal Aviation Regulations, Part 25, Airworthiness Standards: Transport Category Airplanes," Section 25.562, Federal Aviation Administration, Washington, D.C.
8. "Federal Aviation Regulations, Part 27, Airworthiness Standards: Rotorcraft Category Aircraft," Section 27.562, Federal Aviation Administration, Washington, D.C.
9. E. L. Fasanella, R. L. Boitnott, K. H. Lyle, and K. E. Jackson, "Full-Scale Crash Test and Simulation of a Composite Helicopter," *International Journal of Crashworthiness*, 2001 Vol.6 No.4, pp.485-498.
10. K. E. Jackson, "Impact Testing and Simulation of a Crashworthy Composite Fuselage Concept," *International Journal of Crashworthiness*, 2001 Vol.6 No.1, pp.107-122.
11. Fasanella, E. L. and Jackson, K. E., "Crash Simulation of a Vertical Drop Test of a B737 Fuselage Section with an Auxiliary Fuel Tank," Proceedings of the Third Triennial Aircraft Fire and Cabin Safety Conference, Atlantic City, NJ, October 22-25, 2001.
12. Kellas S., Knight, N.F., Jr., "Design, Fabrication and Testing of Composite Energy-Absorbing Keel Beams for General Aviation Type Aircraft," Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, AIAA-2002-1529, Seattle, WA, April 16-19, 2001.
13. Stockwell, A. E., "Evaluation of Modeling and Simulation Tools and

- Techniques for an Analytical Study of the Lear Fan Impact Test," NASA/CR-2002-211457, March 2002.
14. Lyle, K. H., Bark, L. W., "Data Reduction and Its Impact on Test Analysis Correlation," Proceedings of the Third Triennial Aircraft Fire and Cabin Safety Conference, Atlantic City, NJ, October 22-25, 2001.
 15. Memorandum of Agreement between the Federal Aviation Administration and the National Aeronautics and Space Administration concerning Accident and Incident Mitigation Research, MOA Number: FNA/08-01-01, Effective dates: June 21, 2001 - June 21, 2006.
 16. Jackson, K. E. and Fasanella, E. L., "Crash Simulation of a Vertical Drop Test of a B737 Fuselage Section with Overhead Bins and Luggage," Proceedings of the Third Triennial Aircraft Fire and Cabin Safety Conference, Atlantic City, NJ, October 22-25, 2001.
 17. Powers, M., "Material Characterization of Polyurethane Foam under Hydrostatic Loading," AIAA Mid-Atlantic Region I Student Conference, West Virginia University, WV, April 6-7, 2001.
 18. Jackson, K. E., "Analytical Crash Simulation of Three Composite Fuselage Concepts and Experimental Correlation," Journal of the American Helicopter Society, Vol. 42, No. 2, April 1997, pp. 116-125.
 19. Kellas, S., Mitcheltree, R. A., "Energy Absorber Design, Fabrication and Testing for a Passive Earth Entry Vehicle," Proceedings of the 42nd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, AIAA-2002-1224, Seattle, WA, April 16-19, 2001.
 20. Desjardins, S.P., Zimmermann, R. E., Bolukbasi, A. O., et al., "Aircraft Crash Survival Design Guide," Volume I - VI, USARTL TR-89-D-22, Applied Technology Laboratory, U.S. Army Research and Technology Laboratories, Fort Eustis, VA, December 1989.